



# Lateral Load Testing of the Advanced Stirling Convertor (ASC-E2) Heater Head

Free-piston Stirling convertors are fundamental to the development of NASA's next generation of radioisotope power system, the Advanced Stirling Radioisotope Generator (ASRG). The ASRG will use General Purpose Heat Source (GPHS) modules as the energy source and Advanced Stirling Convertors (ASCs) to convert heat into electrical energy, and is being developed by Lockheed Martin under contract to the Department of Energy. Achieving flight status mandates that the ASCs satisfy design as well as flight requirements to ensure reliable operation during launch. To meet these launch requirements, GRC performed a series of quasi-static mechanical tests simulating the pressure, thermal, and external loading conditions that will be experienced by an ASC-E2 heater head assembly. These mechanical tests were collectively referred to as "lateral load tests" since a primary external load lateral to the heater head longitudinal axis was applied in combination with the other loading conditions. The heater head was subjected to the operational pressure, axial mounting force, thermal conditions, and axial and lateral launch vehicle acceleration loadings. To permit reliable prediction of the heater head's structural performance, GRC completed Finite Element Analysis (FEA) computer modeling for the stress, strain, and deformation that will result during launch. The heater head lateral load test directly supported evaluation of the analysis and validation of the design to meet launch requirements. This paper provides an overview of each element within the test and presents assessment of the modeling as well as experimental results of this task.



# **Lateral Load Testing of the Advanced Stirling Convertor (ASC-E2) Heater Head**

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# Introduction

- Objective: To validate the ASC-E2 heater head design to meet launch requirements for the Advanced Stirling Radioisotope Generator (ASRG)
  - Launch requirements were mandated by AFSPCMAN 91-710 V3 (Range Safety User Requirements)
- GRC performed tests subjecting an ASC-E2 heater head assembly to the operational pressure, axial mounting force, thermal conditions, and axial and lateral launch vehicle acceleration loadings that will be experienced during launch
  - Stress, strain, and deflection were measured at key locations
  - The load values and load application points were documented by Lockheed Martin in the Program Information Request/Release (PIR) for derivation of loads to be used for the heater head lateral load test
- A secondary objective of this test was to qualify the Finite Element Analysis (FEA) used to predict the stress, strain, and deflection

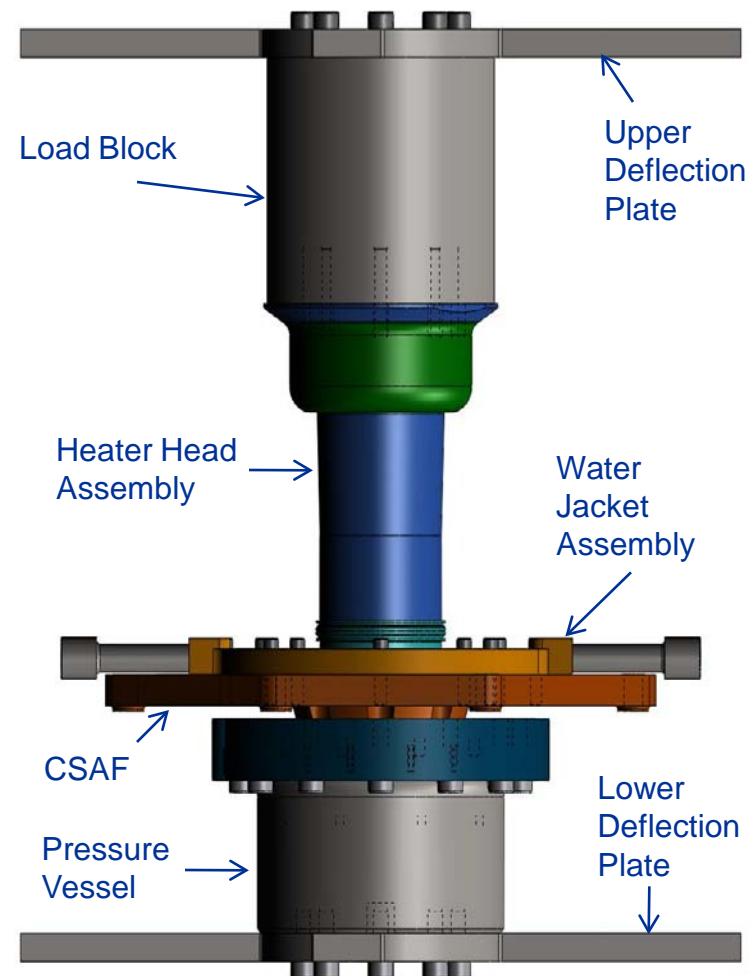
The heater head lateral load test directly supported evaluation of the analysis and validation of the design to meet launch requirements

# Test Article Design

## The Heater Head Lateral Load

### Test Article includes:

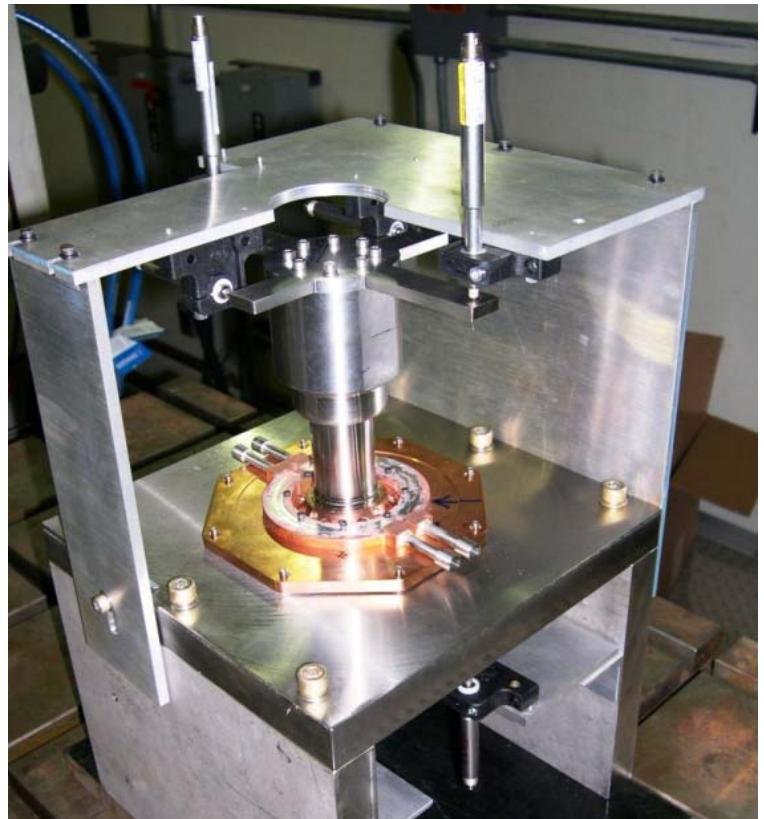
- Heater Head Assembly
- Transition Assembly
- Cylinder Assembly
- Cold Side Adapter Flange (CSAF)
- Pressure Vessel
- Water Jacket Assembly
- Load Block
- Deflection Plates



# Test Fixture Design

The Heater Head Lateral Load Test Fixture includes:

- LVDT Mounting Plates
- LVDT Mounting Plate Brackets
- LVDT (Linear Variable Differential Transformer) Displacement Sensors
- Mounting Plate
- Mounting Plate Stands



# Test Machine and Instrumentation

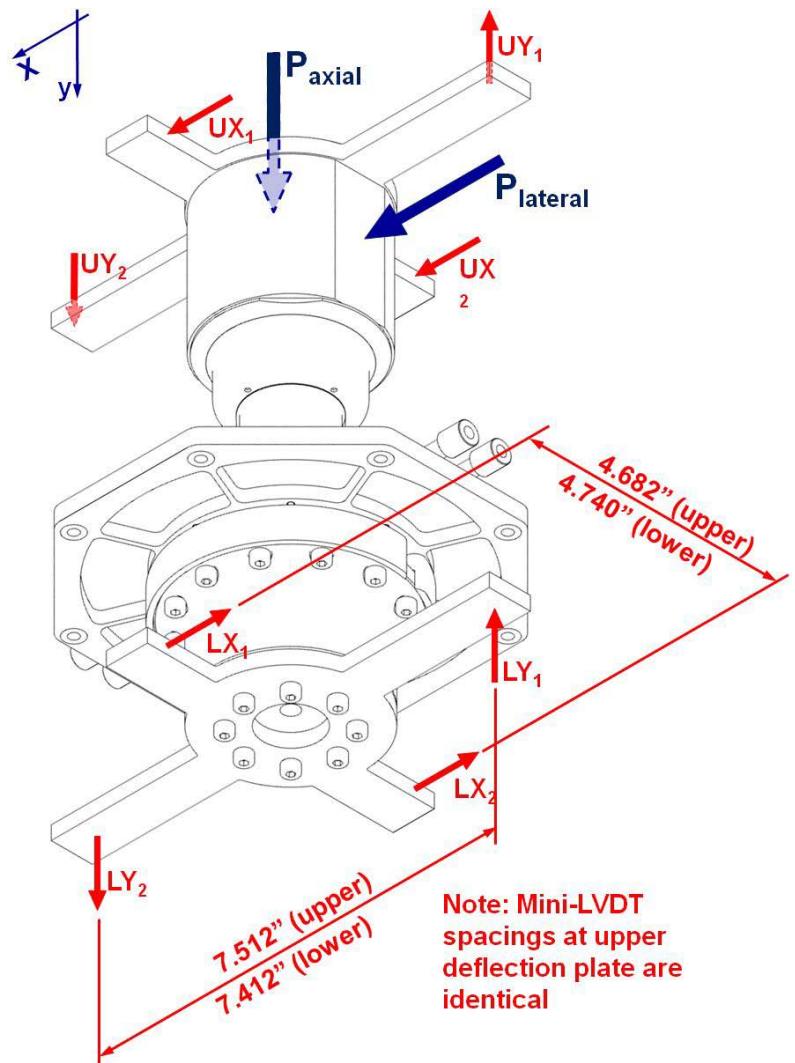
## Structural Loads

- Instron hydraulic in-plane biaxial load frame
  - Used to apply axial and lateral loads
  - Actuators are capable of 100K-pound force
- The axial and lateral loads were controlled and measured using two 2,500-pound-capacity load cells for better accuracy
- A dummy test article was used to verify the closed-loop PID control system
- 12.5K-pound load cells were used to provide back-up data



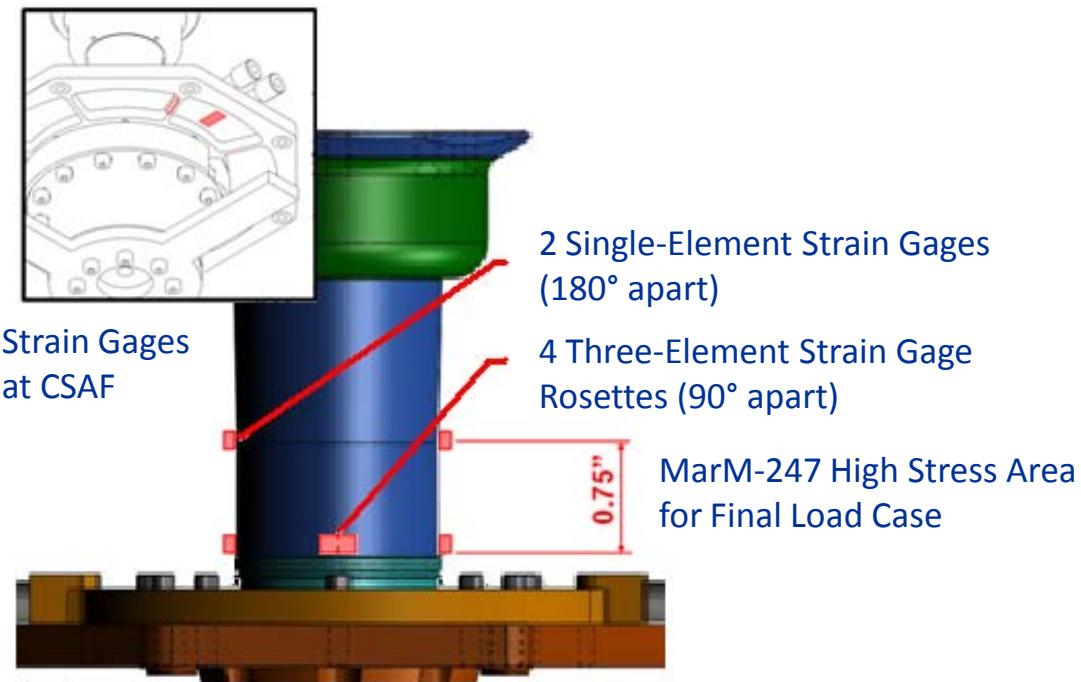
# Instrumentation – Location of LVDT's

- Instrumentation recorded test article axial & lateral deflections and rotations
  - 0.080" high-precision mini-LVDT's for excellent resolution of displacements
  - Four LVDTs were mounted on the upper deflection plate
    - Two LVDTs were mounted laterally and measured lateral deflection and rotation
    - Two LVDTs were mounted axially and measured axial deflection and rotation
  - Four LVDTs were mounted on the lower deflection plate
    - Deflections and rotations were measured similarly



# Instrumentation – Location of Strain Gages

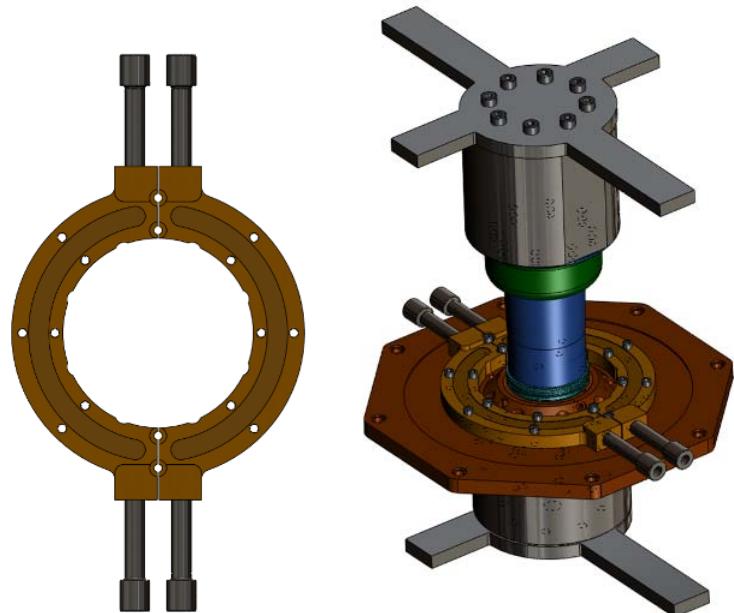
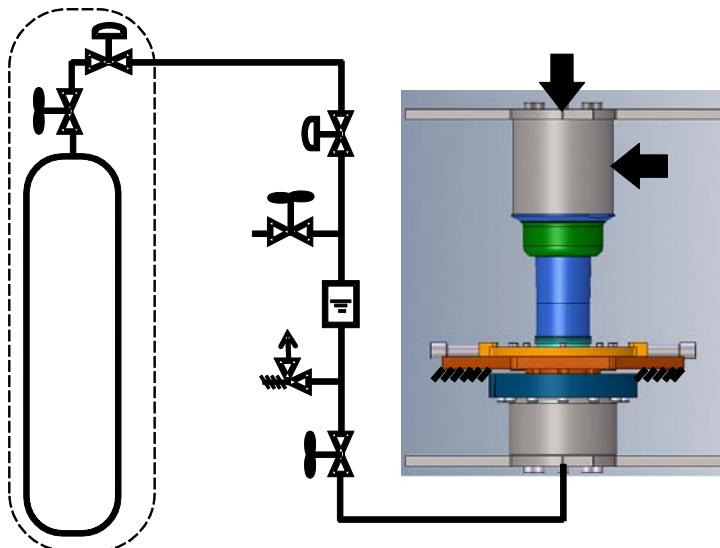
- Instrumentation recorded strains at critical locations to determine yield
  - Four three-element strain gage rosettes were located near the predicted highest stress area on the MarM-247 heater head
  - Two single-element strain gages measured principal strains at the predicted high stress area
  - One rosette and one single-element gage measured strains in the CSAF component



# Test Methods

## Pressure and Temperature

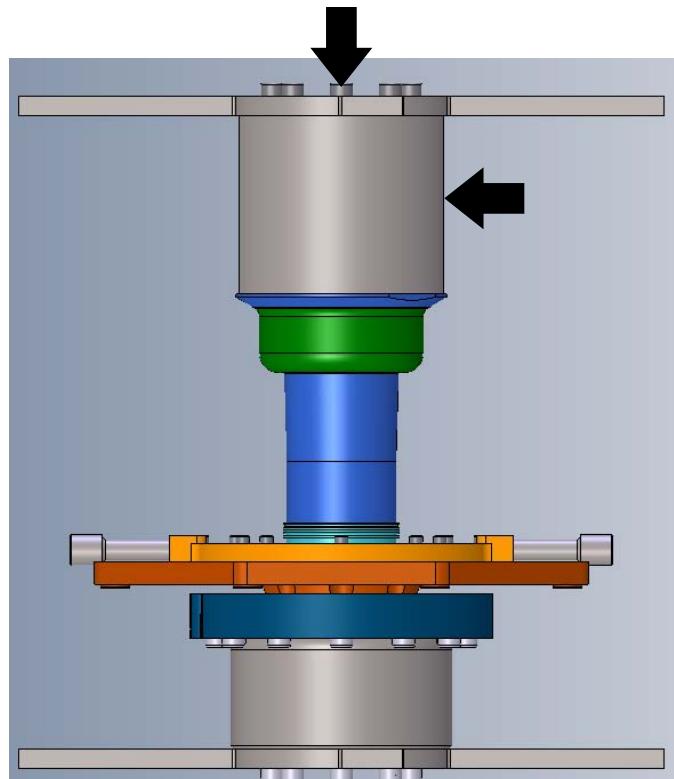
- Pressure - Maximum internal operating pressure expected during launch
  - Internal pressure is provided by local helium K-bottle system
- Temperature - 100 °C at the rejector braze location
  - A water jacket assembly was fixed firmly to the top side of the CSAF to control the rejector temperature
  - Contains an open channel for heated ethylene glycol



# Test Methodology

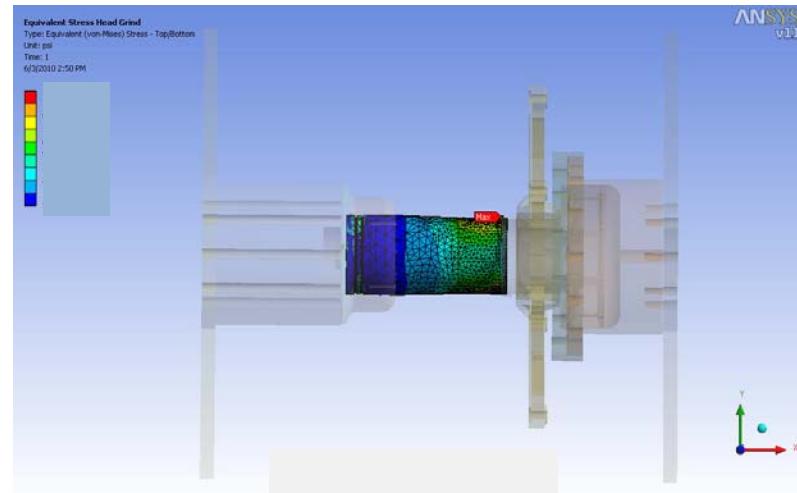
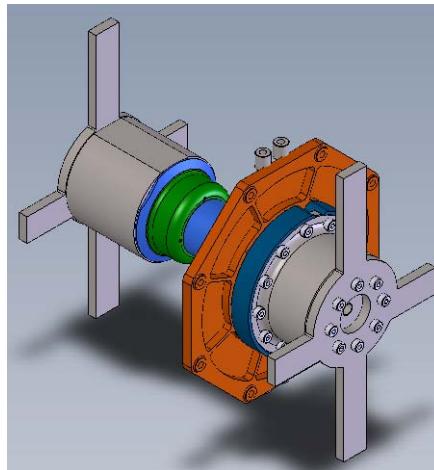
## Load Cases

- The heater head test article was tested in three combined external load cases
  - Load Case 1 – Maximum expected flight axial compressive load
  - Load Case 2 – Nominal flight axial load plus maximum expected flight lateral load
  - Load Case 3 – Nominal flight axial load plus failure-inducing lateral load
- For each load case, ramped steps were increased incrementally until the indicated peak load was reached
- Failure was defined in the test plan by the first occurrence of significant material yielding, material stress rupture, elastic or inelastic buckling, braze failure, fastener fracture, or leakage of the pressurization gas

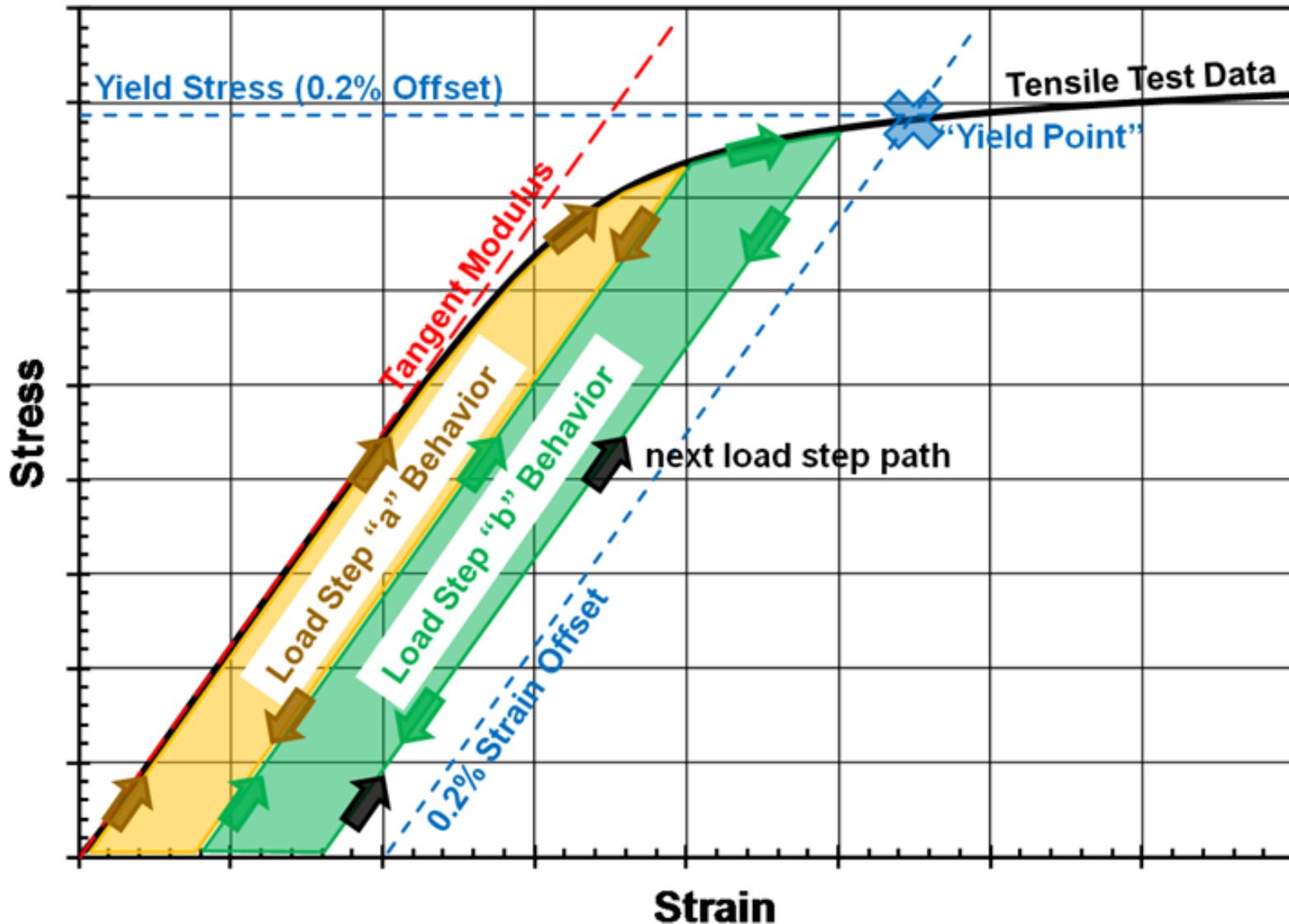


# Analysis

- Pro/E was utilized with ANSYS simulation software for stress, strain, and deflection predictions of the three load cases
- “As-built” configuration geometries of the test article and the test fixture
- The boundary conditions for the load cases were set by fixing the model on eight mounting locations on the CSAF
- Deflection values of the upper and lower deflection plates were determined
  - Used to predict lateral deflection and rotation of the test assembly
- The predicted force and deflection data was used during the actual test to corroborate the experimental results
  - Analysis method used to approximate the test results will be revised based on comparison with the experimental results
  - To reduce risk through greater accuracy in our future structural assessments



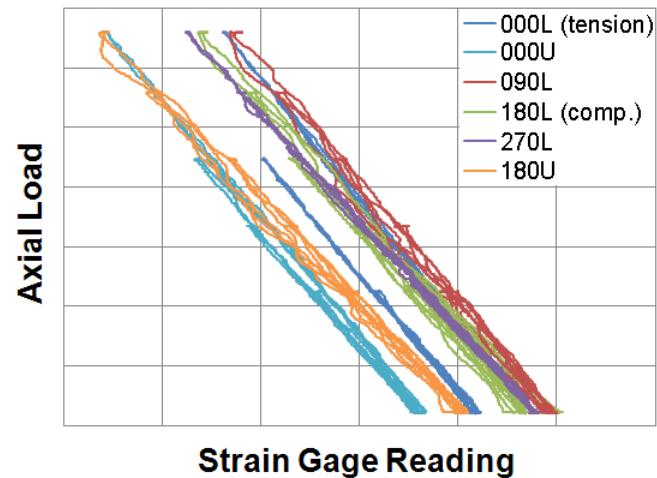
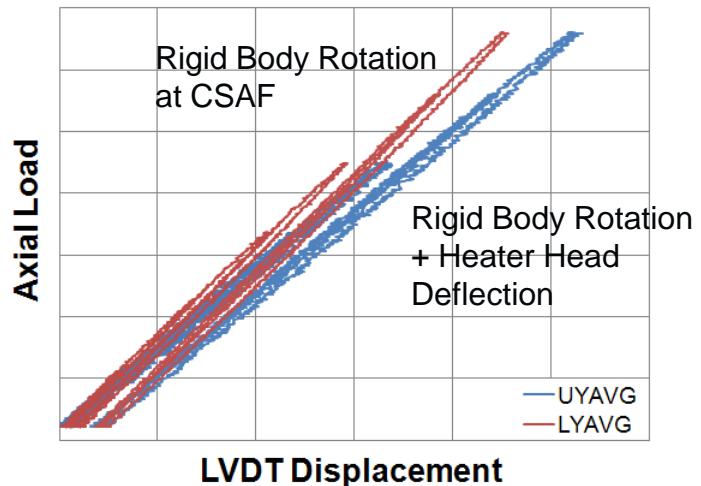
# Similar Material Behavior



# Experimental Results – Load Case 1

- Load Case 1 – Maximum expected flight axial compressive load
  - Majority of deformation (elastic) occurred in CSAF
- Measured axial deflections, although very small in magnitude, exceeded the predicted values
  - Still investigating discrepancy between predicted and measured axial deflections
- The displacements and longitudinal strains showing linear behavior and post-ramp values returning to the initial state indicated no yield

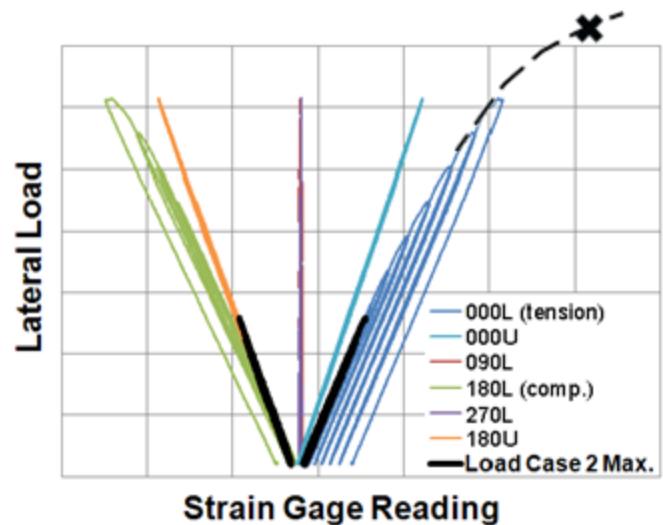
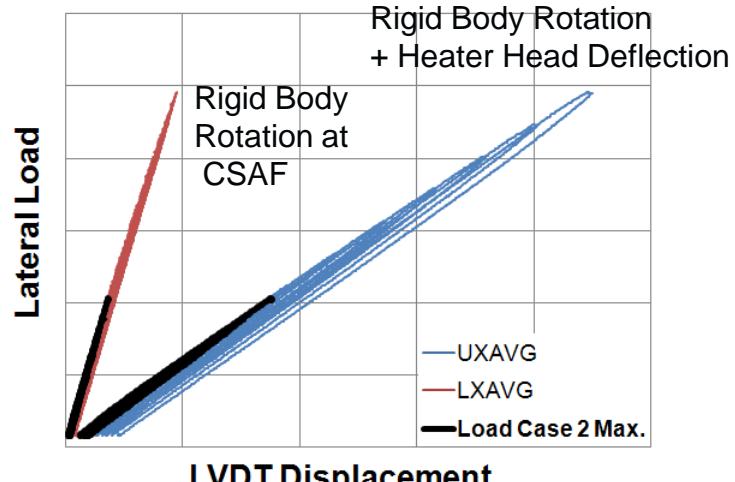
The test article did not fail under the flight-like axial load conditions



# Experimental Results – Load Case 2 & 3a

- Load Case 2 – Nominal flight axial load plus maximum expected flight lateral load
- Measured test article lateral deflections, lateral rotations, and longitudinal strains closely matched predicted values, were linear, and returned to their initial states upon unloading
- Load Case 3a – Initially replicated ramped steps of Load Case 2 while increasing to failure-inducing lateral load
- Even at the maximum lateral load of this case, the measured residual strain at the high stress area remained well below 0.2%, so it is assured that the defined yield strength (0.2% offset) was not reached

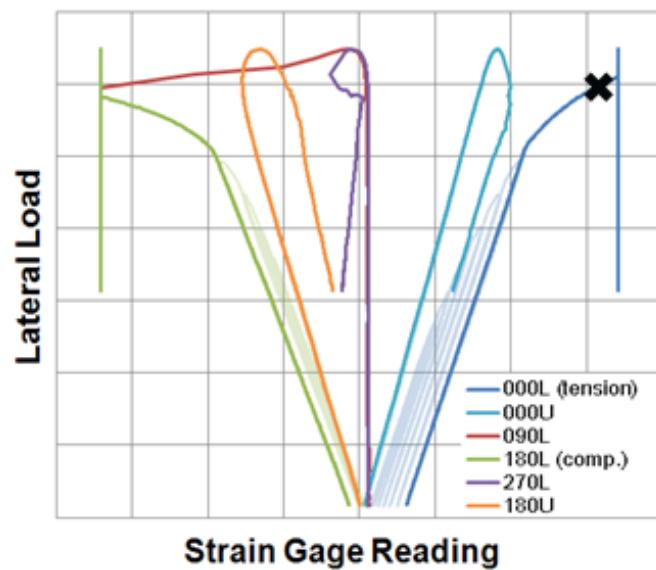
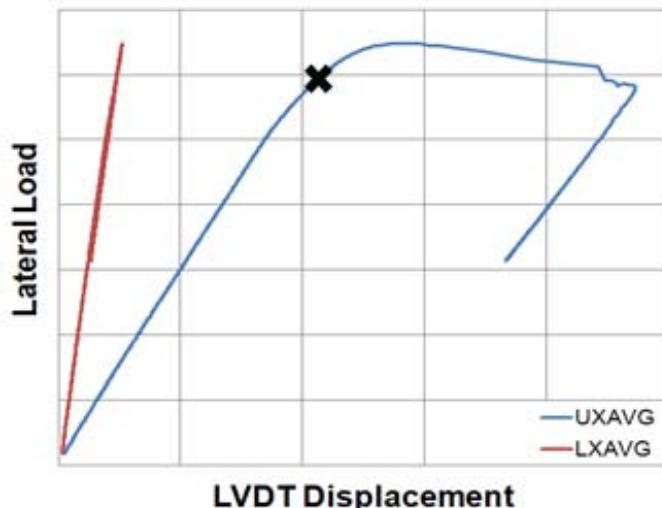
The test article did not fail under the flight-like lateral load conditions



# Experimental Results – Load Case 3b

- Load Case 3b – Nominal flight axial load plus failure-inducing lateral load
  - To induce failure, a final continuous lateral load ramp was imposed on the test article
  - Predicted lateral force was within 25% of measured value
- Deflections and strains were linear through Load Case 3a, and then followed an elastic-plastic curve that may be typical for the MarM-247 heater head material
- CSAF remained elastic
- Still investigating whether initial failure was on the tensile or compressive side
- Failure mode was yielding of the heater head and resultant gross deformation

The test article sustained more than three times the maximum expected mission lateral load while maintaining pressure integrity





# Conclusion

- The Heater Head Lateral Load Test was successful in directly supporting qualification of the ASC-E2 heater head.
- The pressurized test article was exposed to maximum axial compressive and maximum lateral loads anticipated during an ASRG launch, and sustained these load conditions.
- After demonstrating that the test article did not fail under flight-like loads, the test continued with increased lateral loading until the heater head failed, sustaining more than three times the maximum expected mission lateral load while maintaining pressure integrity.

This test result validated the capability of the heater head to meet the launch load requirements with sufficient margin



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